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Clay Mineralogy of Pre-Pennsylvanian Sandstones and Shales of the Illinois Basin

Part II. – Clay Mineral Variations Between Oil-Bearing and Non-Oil-Bearing Sandstones

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Non-Oil-Bearing Sandstones."

Page 5, figure 3. The shale curve has been erroneously plotted.

The kaolinite point on the shale curve should appear at .7 instead of at 1.7.

The chlorite point on the shale curve should appear at 3.6 instead of at 2.6.

Please note this correction on your copy of Circular 287.

Clay Mineralogy of Pre-Pennsylvanian Sandstones and Shales of the Illinois Basin

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Thomas W. Smoot and Kedar Narain

ABSTRACT

The clay mineral compositions of approximately 70 samples of oil-bearing and non-oil-bearing sandstones from the Mississippian Chester Series of the Illinois Basin were determined. Part of the samples are from nine Chester formations located throughout the deep part of the basin; the others are from the Aux Vases Formation in a limited area in Hamilton County.

Easily discernible differences between the compositions of clay minerals from oil-bearing and non-oil-bearing sandstones, apparent in both randomly chosen samples and closely associated samples, are thought to be partly a function of the presence or absence of hydrocarbons. Studies of these differences may be of use in the investigation of the time and mode of oil accumulation.

INTRODUCTION

This report is the second in a series based on a study of approximately 70 clay mineral analyses of outcrop and core samples of pre-Pennsylvanian sandstones and shales of the Illinois Basin. About eighty percent of the samples were from nine formations of the Chester Series of the Mississippian System; the others represent the Valmeyer Series (Mississippian) and the Ordovician and Cambrian Systems.

This report differentiates between the clay mineral suites from oil-bearing and non-oil-bearing sandstones and presents possible explanations for, and the significance of, the differences by comparing the clay mineral assemblages with those commonly found in associated shale facies.

The report is the result of essentially two separate investigations. The first was a study of the clay mineralogy of core samples representing nine Chester formations from locations throughout the deep part of the Illinois Basin (the Fairfield Basin). The second was a study of the Aux Vases Formation (Chester Series) in three closely related oil fields in approximately 30 square miles in Hamilton County, Illinois, in the central portion of the deep part of the basin.

This report is based in part on a thesis by T. W. Smoot submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in geology and in part on a thesis by K. Narain submitted in partial fulfillment of the requirements for the degree of Master of Science in geology, both in the Graduate College of the University of Illinois, 1959.

The authors express their appreciation to Professor R. E. Grim for advice given during all stages of the study.

SELECTION OF SAMPLES

Forty-six samples representing nine formations of the Chester Series (Mississippian System) from 39 locations scattered throughout the deep part of the Illinois Basin (the Fairfield Basin) constitute the basis for part of this report (fig. 1). The samples were chosen to represent the largest geographical distribution of time-rock units using a limited number of samples and to afford comparisons of the clay mineral suites of approximately contemporaneous oil-bearing and non-oil-bearing sandstones and associated shales.

In addition, 26 core samples from 21 locations of the Aux Vases Formation came from the southwest portion of the Bungay Consolidated Pool, the northeast portion of the Dale Consolidated Pool, and the Thackeray Pool (fig. 2) in Hamilton County, Illinois. All of the samples were taken from the lower part of the cores available so that, as far as possible, they were from the same stratigraphic position. Both sandstones and shales were sampled so that any lateral facies present were represented.

As explained in Part I, the central portion of each core was carefully separated from the outer portions and used as the sample in order to minimize contamination by drilling-mud invasion.

SAMPLE PREPARATION

The preparation of the non-oil-bearing sandstone and shale samples is described in detail in Part I. The oil-bearing sandstone samples were prepared in a manner somewhat different from that used for the non-oil-bearing and slightly oil-bearing sandstone samples.

In order to remove the oil from oil-saturated sandstone samples, they were crushed, washed in a Soxhlet extractor with low-boiling petroleum ether for periods ranging between 20 and 48 hours, and then air dried at temperatures slightly higher than room temperature (30° to 34° C) until the petroleum ether had apparently evaporated. These samples were further disaggregated and treated the same as the non-oil-bearing samples (Part I).

CLAY MINERALS PRESENT

A detailed description of the clay mineral groups and subgroups encountered in the samples appears in Part I of this series. It is convenient, however, to

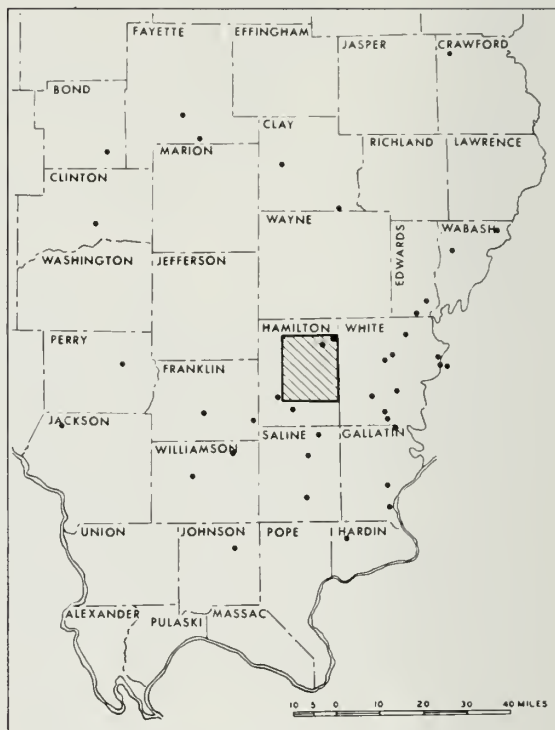


Fig. 1 - Location of Chester samples from the Illinois Basin, with the exception of Aux Vases samples from Hamilton County (cross-hatched).

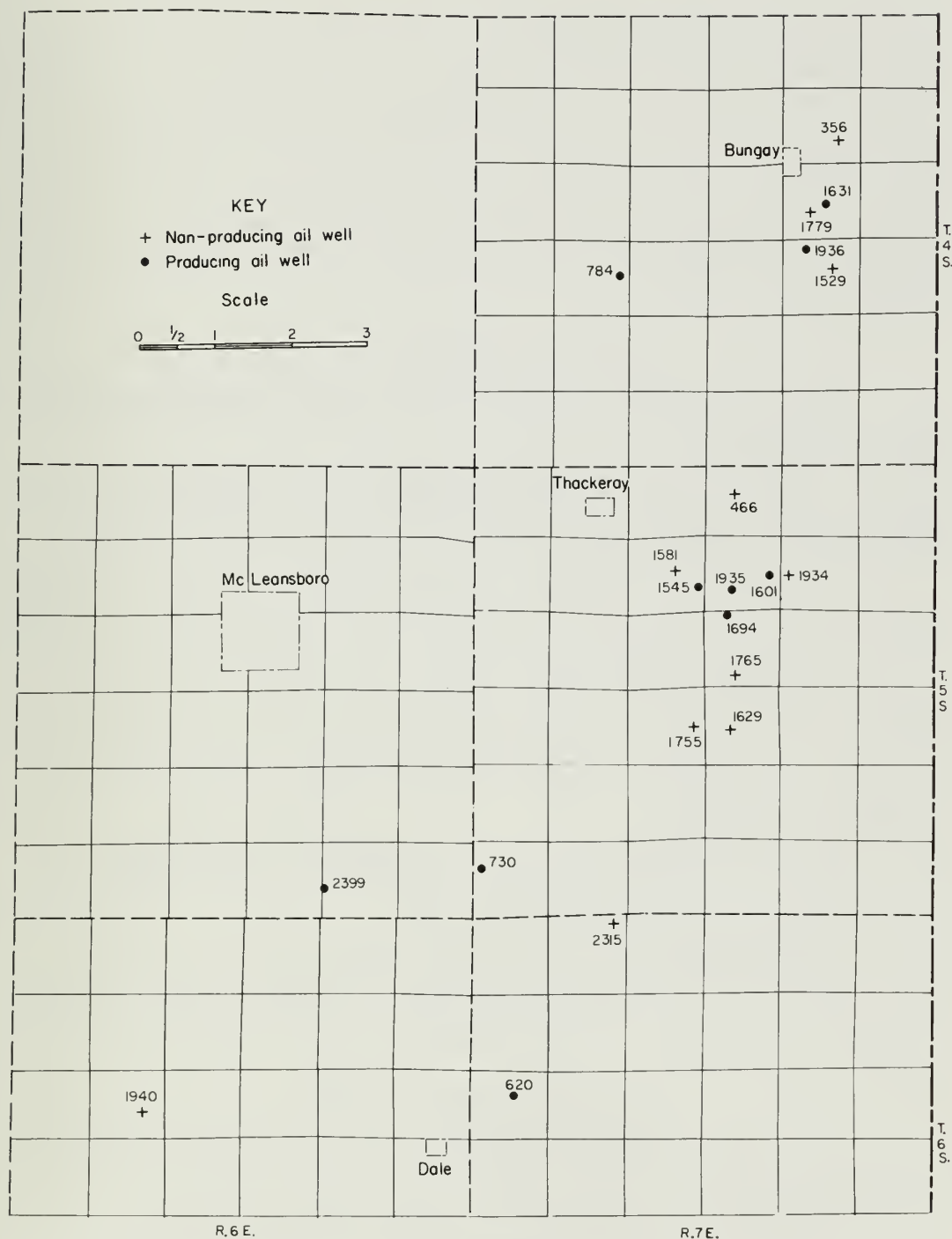


Fig. 2 - Location of samples of the Aux Vases Formation from Hamilton County.

summarize the clay minerals found and to define again the mineralogical terms used.

Five clay mineral groups recognized in the samples are the illite group, the chlorite group, the kaolinite group, the montmorillonite group, and the group composed of mixed-layer undifferentiated material. In the illite group two subgroups are recognized: a) well crystallized illite, and b) a poorly ordered, at least partially expandable, subgroup referred to as illite plus mixed-layer material. Similarly, there are two subgroups which comprise the chlorite group: a) a well crystallized group referred to as chlorite, and b) a mixture of chlorite and at least partially expandable material referred to as chlorite plus mixed-layer material.

The term "all mixed-layer material" as used herein refers to all of the illite plus mixed-layer material, chlorite plus mixed-layer material, montmorillonite, and mixed-layer (undifferentiated) material that is present in a sample, as a single assemblage.

QUANTITATIVE ESTIMATIONS

A detailed explanation of the methods used in making quantitative estimates of the clay minerals is presented in Part I of this series. To summarize briefly, two methods were used.

1) The shales, which are dominantly composed of well ordered illite and chlorite, were estimated quantitatively using the system outlined by Johns et al. (1954). This system is based on a comparison of the first-order peak-area intensities of the clay minerals present.

2) The method used in samples containing a dominant amount of mixed-layer material was one based on a system suggested by Bradley (personal communication, 1958). This system is based on the intensities of first-order peaks of illite, chlorite, glycol-expanded montmorillonite, and the third-order peak of kaolinite. The intensities of each of these peaks were essentially compared to the comparable peak intensities of "pure" samples of each of these minerals. This method permitted more accurate estimates of the relative abundance of the poorly ordered components than could be made using the method outlined by Johns et al. (1954) although the Johns et al. method gave the best results in samples dominated by well ordered clay minerals.

As the Aux Vases samples from Hamilton County are restricted to a small area and to a small stratigraphic zone, it was assumed that the sediments were derived from the same source area and were deposited at about the same time and under essentially the same environmental conditions. Therefore, it was supposed that quantitative variations could be shown by comparing the intensities of the first-order peaks of the various clay minerals. This was done by comparing the areas (as measured above the projected background intensity) comprising the peaks of the various clay minerals. The quantitative estimates were derived using this method.

DISTRIBUTION OF CLAY MINERALS

The investigation of many subsurface samples of sandstones and shales of Chester age has led to some general conclusions pertaining to characteristic clay mineral suites which appear in the different lithologies.

The shales, even those intimately associated with sandstones, are characteristically composed dominantly of illite and chlorite with rarely more than a few parts in ten of illite plus mixed-layer material and of chlorite plus mixed-layer material. Kaolinite and montmorillonite are rarely present.

The clay minerals in the sandstones are mainly illite plus mixed-layer material and kaolinite. Chlorite plus mixed-layer material and illite are commonly present in lesser proportions, and montmorillonite is occasionally present in minor amounts.

Intermediate porous rocks typically exhibit clay mineral compositions gradational between the above two described suites.

The study of these Chester samples also suggests that there is a significant difference between the clay mineral compositions of oil-bearing and non-oil-bearing sandstones. Table 1 presents the clay mineral compositions of 46 core samples of Chester sandstones and shales from the deep part of the Illinois Basin. By comparing the clay mineral compositions of the shales with those of the oil-bearing and non-oil-bearing sandstones of each formation (in formations where such comparisons can be made), it can be seen that the differences most readily apparent are changes in the proportionate amounts of illite, kaolinite, and all mixed-layer material (especially illite plus mixed-layer material). However, the average compositions of the three types of samples is more strikingly exhibited by comparing the average compositions of each type (shown at the bottom of the table).

The differences between the shales and the two types of sandstones (when combined) is striking (Part I). It has been recognized that post-lithification alteration of clay minerals occurs in permeable sediments, not only in outcrop exposures but also in the subsurface. However, there is also a noticeable difference between oil-bearing and non-oil-bearing sandstones that were deposited under approximately the same conditions in a relatively restricted area (the deep part of the Illinois Basin).

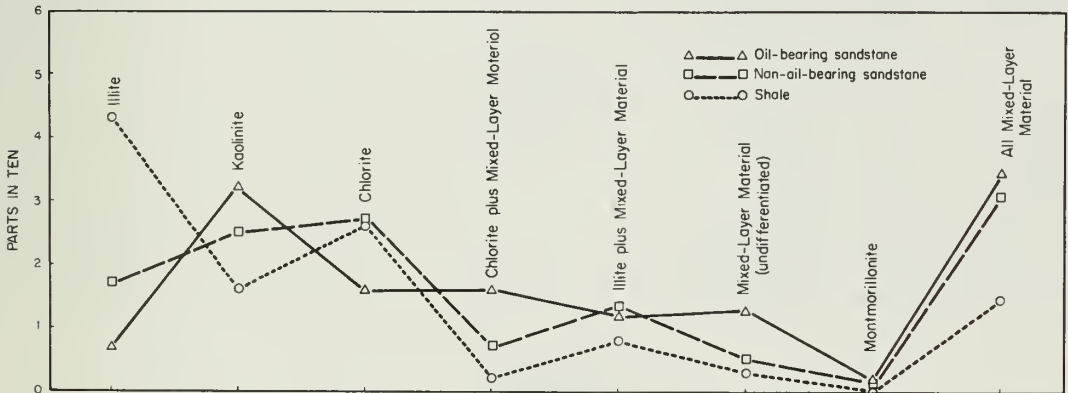


Fig. 3 - Average of clay mineral composition of Chester shales, oil-bearing sandstones, and non-oil-bearing sandstones.

The differences in clay mineralogy between the oil-bearing and non-oil-bearing sandstones, as shown in table 1 and figure 3, are essentially the differences in the relative amounts of the well crystallized three-layer clay minerals present in each. The oil-bearing sandstones generally are composed of only two parts in ten illite and chlorite. The non-oil-bearing sandstones exhibit usually more than twice that amount. Conversely, the oil-bearing sandstones exhibit approximately twice as much all mixed-layer material as do the non-oil-bearing sandstones. Generally, the proportion of kaolinite in the oil-bearing sandstones is significantly greater than that in the non-oil-bearing sandstones.

Table 1. - Clay Mineral Composition of Chester Shales,

Formation and sample	County	Illite	Chlorite	Kaolinite
<u>Degonia</u>				
4D	White	2	5	Tr
1987D	White	1	2	2
309	Gallatin	8	-	1.5
1953D	Posey (Ind.)	4.5	4	.5
<u>Palestine</u>				
2090	White	1.5	1.5	4.5
1032A	Williamson	-	-	2.5
487	Saline	1.5	2	4+
133E	Williamson	1	5.5	1.5
1032B	Williamson	2	5.5	1+
<u>Waltersburg</u>				
CS1	White	.5	4	2.5
1716	Posey (Ind.)	1	4	Tr
1692	Edwards	1	3	3
133F	Williamson	1	5	1
308	Wabash	4	3	2
<u>Tar Springs</u>				
1427	Franklin	1	1	5
2191	White	1	2	2
1840	White	-	1	4
1427B	Franklin	-	-	7
538	Hamilton	?	?	Med.
1000	Saline	1.5	1.5	5
1853A	Gallatin	3	Tr	3
<u>Cypress</u>				
501	Perry	1	2.5	2
1073	Clinton	2	2	1.5
397	Crawford	1	Tr	5
1201	Edwards	2	3.5	1.5
133.1	White	1	2	4
<u>Paint Creek</u>				
432	Hamilton	.5	2.5	-
1339	White	1.5	3	4.5
2578PC	Hardin	8	-	-
1618	Fayette	4.5	Tr	-

Oil-Bearing Sandstones, and Non-Oil-Bearing Sandstones

Illite plus mixed-layer material	Chlorite plus mixed-layer material	Montmorillonite	Mixed-layer material (undifferentiated)	Lithology *
<u>Degonia</u>				
1	1	Tr?	Tr	N-o-b ss
1.5	3.5	Tr	-	O-b ss
Tr	Tr	-	-	Shale
.5	.5	Tr?	-	Shale
<u>Palestine</u>				
.5	1	.5	-	O-b ss
-	-	-	7.5	O-b ss
.5+	1.5+	-	-	N-o-b ss
1	Tr	-	-	N-o-b ss
1	Tr	Tr?	-	Shale
<u>Waltersburg</u>				
.5	2	Tr?	-	O-b ss
-	-	-	4.5	Slightly O-b ss
Tr	Tr	?	2	N-o-b ss
Tr	.5	-	2	Shale
1	-	-	-	Shale
<u>Tar Springs</u>				
.5	2	-	.5	O-b ss
2	3	-	-	O-b ss
-	-	-	5	O-b ss
1.5	1.5	-	-	O-b ss
Weak	Weak	?	Weak	O-b ss
1	1	-	-	Argillaceous ss
4	-	-	-	N-o-b ss
<u>Cypress</u>				
2	2	Tr	-	O-b ss
1.5	2.5+	Tr?	-	O-b ss
2	2	-	-	O-b ss
2	Tr	Tr	-	N-o-b ss
2	1	-	-	N-o-b ss
<u>Paint Creek</u>				
1	.5	-	5	O-b ss
Tr	Tr	-	-	N-o-b ss
.5	-	1.5?	-	Shale (mud)
4.5	-	-	-	Shale

* O-b ss = Oil-bearing sandstone; N-o-b ss = Non-oil-bearing sandstone.

Table 1. -

Formation and sample	County	Illite	Chlorite	Kaolinite
<u>Bethel</u>				
2396	Wabash	-	2	3
2392	Clay	.5	3	4
1343	Jackson	Med.	Weak	Weak
2605	Bond	.5	2	2.5
133.2	White	1.5	5.5	2
2507	White	3.5	6	-
2634	Fayette	1.5	7	Tr
<u>Renault</u>				
2365	Franklin	8.5	-	-
2750	Hamilton	4.5	5.5	-
<u>Aux Vases</u>				
136.1	Hamilton	4	4	1
2634	Fayette	2+	4.5	2+
1987	White	1.5	4	2-
2789	White	2.5	4+	1
2798	Saline	5.5	4	-
3231	Clay	5+	4	-
2336	Johnson	8	1	-
<u>Averages</u>				
Oil-bearing sandstone		.7	1.6	3.2
Non-oil-bearing sandstone		1.7	2.7	2.5
Shales		4.3	3.6	.7

As the samples discussed above are from various facies and formations, the differences between the oil-bearing and non-oil-bearing sandstones may be a function of availability of samples, of differences in source areas or environments of deposition, or of other variables which had little or nothing to do with the presence or absence of oil. A very detailed study of samples from the Thackeray Pool and parts of the Dale and Bungay Consolidated Pools representing a limited period of deposition over a small area in which the sediments were probably derived from essentially the same source areas and deposited under essentially the same environments of deposition should reduce these variables to a minimum. Thus, differences between oil-bearing and non-oil-bearing sandstones would strongly favor a connection with the presence or absence of oil.

Table 2 represents the clay mineral compositions of the 26 samples which are from Thackeray Pool and portions of the Bungay and Dale Consolidated Pools. Table 2 differs from table 1 in that the small proportions of montmorillonite found in the samples have been included in the proportion of mixed-layer (undifferentiated)

Continued.

Illite plus mixed-layer material	Chlorite plus mixed-layer material	Montmorillonite	Mixed layer material (undifferentiated)	Lithology
<u>Bethel</u>				
3	2	-	-	O-b ss
1	1	-	-	O-b ss
Weak	Weak	-	-	N-o-b ss
2.5	2.5	-	-	N-o-b ss
-	-	-	1	Shale
-	-	-	.5	Shale
1	Tr	-	-	Shale
<u>Renault</u>				
1	Tr	-	Tr	Shale
-	-	-	Tr	Shale
<u>Aux Vases</u>				
-	-	Tr	Tr	Shale
-	-	-	1	Shale
2.5+	Tr	Tr	-	Shale
Tr	1	1	-	Shale
-	-	Tr	.5	Shale
.5	Tr	-	-	Shale
.5	.5	-	-	Shale
<u>Averages</u>				
1.2	1.6	.1	1.3	
1.3	.7	-	.5	
.8	.2	.1	.3	

material. The presence of distinct montmorillonite was noted only in sample 2315, but possible trace occurrences were noted in samples 1581 and 1765, and therefore it is included as an undifferentiated mixed-layer component. No kaolinite was found in any of these samples, therefore kaolinite was deleted from table 2. W. A. White and W. E. Parham (personal communication, 1959) have convincing evidence, based on studies of the Pennsylvanian sediments of the Illinois Basin, that kaolinite is generally restricted to near-shore environments. Smoot (1959a) has also presented evidence of this for the pre-Mississippian rocks of the Illinois Basin. Therefore, it may be concluded that the absence of kaolinite in the Hamilton County Aux Vases samples indicates that the samples were deposited in an off-shore environment.

Tables 1 and 2 exhibit similar differences among the clay mineral compositions of the shales, the oil-bearing sandstones, and the non-oil-bearing sandstones. It is apparent from the samples that in this limited area, the two sandstone types represented are more nearly alike in composition than are the samples discussed

Table 2. - Clay Mineral Compositions of Aux

Sample (see fig. 2)	Illite	Chlorite
<u>Bungay Consolidated Pool</u>		
1631A	1+	1
1779	2+	2+
1784	5+	.5
356	3.5	Tr
1631B	4+	1+
461	4+	2
936	6.5	-
1529	5	.5
<u>Dale Consolidated Pool</u>		
2399	1	Tr
620	1	1
730	1+	1
1755A	6	Tr
1941A	1	Tr
1941B	6	1.5
2315A	3.5	1.5+
1755B	6	1
2315B	7-	Tr
<u>Thackeray Pool</u>		
1545	2+	2
1601	5.5	Tr
1694	2.5	1.5
1935	2-	1.5+
1581A	2.5	1.5
1934A	5.5	1+
1581B	6.5	Tr
1934B	7	Tr
1765	7	Tr
<u>Average</u>		
Oil-bearing sandstones	2.4	1.1
Non-oil-bearing sandstones	4.4	1.1
Shales	6.5	.5

Vases Sandstones and Shales in Hamilton County

Illite plus mixed-layer material	Chlorite plus mixed-layer material	Mixed-layer material (undifferentiated)	Lithology*
<u>Bungay Consolidated Pool</u>			
1.5+	1+	4.5	O-b ss
1.5	1	3+	O-b ss
2+	Tr	2	O-b mica ss
3+	1-	2	N-o-b ss
2.5	Tr	1.5	N-o-b argil ss
2	Tr	1+	N-o-b ss
1	1.5	1	Shale
3	Tr	1+	Shale
<u>Dale Consolidated Pool</u>			
2	1+	5.5	O-b ss
2	1	5	O-b ss
3-	1	4-	O-b ss
2+	Tr	1	N-o-b mica ss
4	1	4+	N-o-b ss
1.5	Tr	Tr	N-o-b mica ss
1.5+	1	1+	N-o-b ss
2	Tr	1	Shale
2-	Tr	1-	Shale
<u>Thackeray Pool</u>			
2.5	-	3+	O-b ss
2	Tr	1.5	O-b argil ss
3.5	1	1.5	O-b ss
2+	1-	3.5	O-b ss
2.5	1	2.5	N-o-b ss
1+	-	2	N-o-b ss
1	Tr	1+	Shale
1+	Tr	Tr	Shale
1+	Tr	1	Shale
<u>Average</u>			
2.2	.8	3.4	
2.3	.5	1.8	
1.6	.4	.9	

* O-b ss = Oil-bearing sandstone
 N-o-b ss = Non-oil-bearing sandstone

Mica = micaceous
 Argil = argillaceous

above from a much larger area. The average Hamilton County sandstone sample has approximately the same proportions of chlorite, illite plus mixed-layer material, and chlorite plus mixed-layer material. The most noticeable differences are in the illite and the mixed-layer (undifferentiated) material proportions. The non-oil-bearing sandstones have approximately twice the proportion of illite as the oil-bearing samples; the oil-bearing sandstones have approximately twice the proportion of mixed-layer (undifferentiated) material as those without oil. These differences are also demonstrated graphically in figure 4 which represents the average clay mineral compositions of the shales, oil-bearing sandstones, and non-oil-bearing sandstones. The most striking differences are between the proportions of illite and all mixed-layer materials.

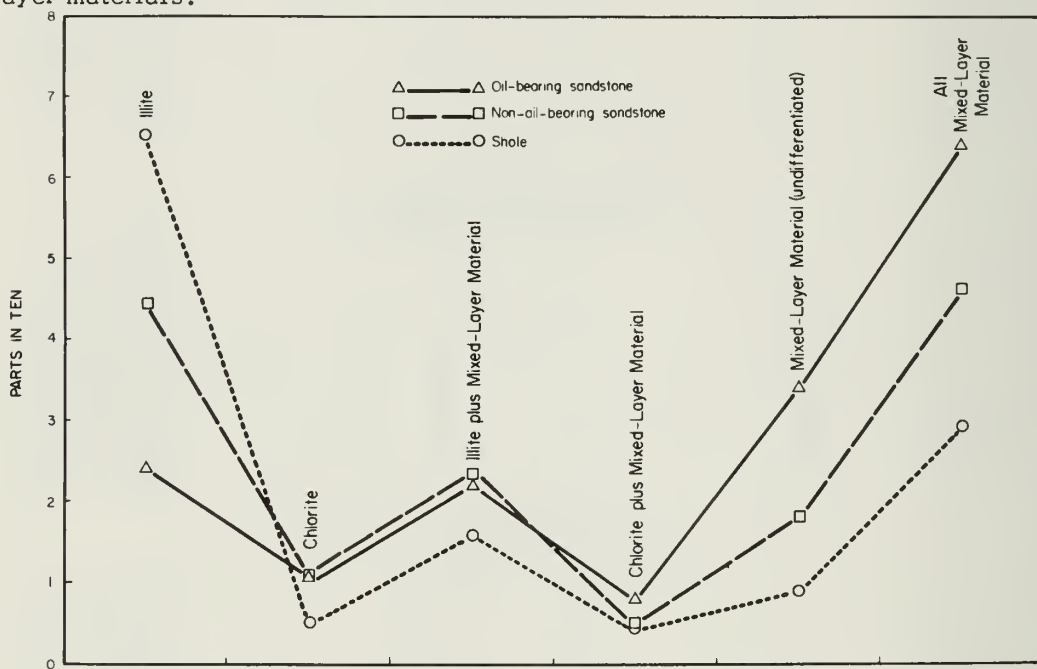


Fig. 4 - Average clay mineral composition of shales, oil-bearing sandstones, and non-oil-bearing sandstones of the Aux Vases Formation from Hamilton County.

DISCUSSION

On the basis of the clay mineral analyses presented here, it seems apparent that the differences between clay mineral compositions of oil-bearing and of non-oil-bearing sandstones are due, at least in part, to the presence of oil. These variations are characterized by the proportionate differences in well crystallized three-layer clay minerals. The non-oil-bearing sandstones have appreciably higher proportions of illite and, generally, chlorite; oil-bearing sandstones are proportionately higher in kaolinite (if present).

In many instances, especially among the Hamilton County samples, these differences are apparent in samples of sediments which were probably deposited under the same conditions and derived from the same source areas. It would seem, therefore, that the differences are not inherent, but that they developed during some period after deposition. These observations appear to have some bearing on the mode and time of accumulation of oils.

The average clay mineral composition of very near-shore deposits in the Illinois Basin (Smoot 1959b) is similar to that of the oil-bearing sandstones as shown in tables 1 and 2. This may suggest that the clay mineral suites associated with oil accumulations, even though found in off-shore facies, are more nearly like the clay mineral suites originally introduced into the sedimentary basin than are the non-oil-bearing clay suites.

Degraded three-layer clay minerals, which would be expected to have been a major portion of the clay mineral suite introduced into the Illinois Basin during Chester time, would have a relatively high crystallite charge. In the sedimentary basin this charge would be satisfied by the interlayer adsorption of cations. If organic cations were available, they would satisfy the cation deficiency of the degraded clays. Ensminger and Giesekeing (1942) suggested that certain adsorbed organic compounds can reduce the exchange capacity of clays, which otherwise have high exchange capacities, by blocking the interlayer positions. Montmorillonitic clay minerals generally have the highest exchange capacities and, therefore, would be prone to adsorb organic compounds that might be available more readily than better crystallized illitic or chloritic clay minerals. If such a situation existed, the clays closely associated with the organic compounds would have been prevented from regeneration, even after burial, whereas the clays not associated with the organic compounds may have become better organized during diagenesis and burial.

The idea that oil-bearing clays have been closely associated with organic compounds since, essentially, their deposition has merit only if it can be shown that 1) the hydrocarbons were available at the time of or soon after deposition, and 2) that the oil accumulations now found with these clays were in place soon after deposition. If these points could be proved, probably it could also be proved that oil accumulations are not the product of migration. Because the non-migration accumulation idea is outweighed by the evidence for accumulation by migration, it must be assumed at present that most oil accumulations are the product of migration after lithification and subsequent structural deformation.

As discussed in Part I and above (under "Distribution of Clay Minerals"), many investigators have recognized that post-lithification alteration of clay minerals occurs in permeable sediments. Such alterations are generally degradational, brought about by the circulation of fluids, the chemical composition of which changes from time to time. If this is so, it seems logical that the greater the permeability the greater the amount of circulation, the greater the changes in composition, and, therefore, the greater the amount of degradation of the clay minerals.

If oil migrates mainly by the action of fluid movement after structural shifts of position, it seems reasonable that the oil would migrate along the most permeable paths available and be entrapped in the most permeable positions along the structures. Hence, this would be a reason for the differences of clay minerals between oil-bearing and associated non-oil-bearing sandstones. This idea is further strengthened by the fact that, at some places, non-oil-bearing permeable sandstones have clay mineral suites very similar to those of oil-bearing sandstones (for example, compare samples 2090, 487, and 501, table 1, and 1941A, 1545, and 1581A, table 2). This suggests that possibly the same amounts of post-lithification degradation occurred but that, in some instances, the degrading fluids did not supply oil to the clays at a later time.

A comparison between the clay mineral suites in the oil-bearing and non-oil-bearing sandstones, especially in the Hamilton County Aux Vases samples, suggests that some of the clays may have been at least partly degraded between the

time of lithification and the time of oil accumulation. The strong affinity of montmorillonite for organic compounds is known (Cowan and White, 1958) and so it seems logical to suppose that the clay mineral mixtures common in oil-bearing sandstones and having montmorillonite as a common component would have essentially this same strong affinity. Thus, it seems unlikely that once the exchange positions on these mixtures were satisfied by hydrocarbons, they would again be replaced. Therefore, after oil-accumulation, it seems improbable that further degradation could take place.

If the reasoning is valid, it follows that if degradation of clay minerals took place it must have happened before the oil accumulated. This suggests that oil accumulation occurs after lithification. If formation-fluid circulation is brought about by structural readjustments, this suggests that oil accumulation may occur after structural adjustment and after a certain amount of non-oil-bearing, degrading fluid had passed through the reservoir. If a fairly constant rate of movement (circulation) can be assumed, then time is directly proportional to distance. Thus, it is suggested that in some instances oil may have migrated over relatively long distances. Conversely, if the clay mineral suites are very degraded, oil-bearing reservoirs exhibiting clay mineral suites composed of comparatively well crystallized clay minerals may have obtained oil from nearby source sediments.

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